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The impact of Collembola on humification and mineralization of soil organic matter

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With 3 figures

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1. Introduction

It is generally accepted that the direct effects of the activities of Collembola on the break down of soil organic matter are small compared to the indirect effects (Ineson *et al.* 1982; Cancela da Fonseca *et al.* 1983; Seastedt 1984; Anderson *et al.* 1983; Visser 1985). It is the feeding habits of Collembola that affect the breakdown of soil organic matter indirectly. Most studies, like those of Cancela da Fonseca *et al.* (1983) and Seastedt (1984), mention the resemblance in feeding behaviour between different species of Collembola. Only occasionally are differences in feeding habits between Collembola, depending on their size and lifeform (as described by Gisin 1943), reported (e.g. by Schaller 1950; Bockemühl 1966, 1978; Bödvarsson 1970; Mignolet 1972; McMillan 1975; Petersen 1980 and Vegter 1983). These authors showed that the smaller euedaphic species live in small pores, mostly deeper in the soil, and feed on dispersed humus mixed with mineral soil particles. The larger soil dwelling species live in larger pores and cavities, near the soil surface, and are selective fungivores. Differences in feeding habits of Collembola have not been demonstrated to have different impacts on breakdown of soil organic matter.

Breakdown of soil organic matter can be divided in processes of mineralization and humification. Decomposition rate and humus accumulation are interrelated and depend on the structure and quality of the added organic matter. Janssen (1984) described decomposition rates and their links with the age of the organic matter. He used a humification coefficient which is the fraction of the added organic matter that is still present after one year. Humification coefficients were calculated from field experiments by Kolenbrander (1969) and they help in understanding the processes of humification and mineralization of the soil organic matter. The amount of breakdown of organic matter in the soil can be measured by the mineralization process, which is reflected by the loss of both nitrate and ammonium. The longer organic matter has been breaking down in the soil, the slower the mineralisation process becomes (Janssen 1984). Determination of the humification processes is more difficult.

In the experiment described here the main aim was to investigate the impact of Collembola on the two processes of humification and mineralization of organic matter. The two fields which were surveyed represent, in the crop rotation, the maximal and minimal provision of organic matter input. During winter both fields were left fallow. Sampling determined both the inorganic nitrogen concentration and the population sizes of the collembolan species.

2. Materials and methods

2.1. The site and sampling period

The research was carried out on the biodynamic part of the experimental farm "Development of Farming System" (OBS) in Nagele (The Netherlands). On this part the soil fauna is not influenced by pesticide application. The crop rotation was: Potatoes for human consumption — winter wheat —

winter-barley — 1 year lucerne-clover ley — fodderbeets/sugarbeets — winter-wheat — oats — 3 year clover-grass ley. The clay content of the soil is 30%, the $CaCO_3$ content is 8.7%, and the *p*H is 7.4.

Sampling took place on five occasions (13 October and 9 November 1983, 16 February, 13 March and 4 June 1984). In February only the springtail population was sampled; on the other four occasions, the springtails were sampled and nitrogen concentrations were determined.

One set of samples was taken after the third year of the clover-grass ley. The ley received 10 t $\times$ ha^{-1} of heather compost (11% organic matter; 0.27% nitrogen) and 25 t $\times$ ha^{-1} loose stable manure (17.4% organic matter; 0.6% nitrogen) on 15 October 1983. After manuring, the field was cultivated and ploughed to a depth of 25 cm. During April 1984 potatoes were planted. The other set of samples was taken from a field cropped with winter-wheat in 1983. After stubble ploughing in August, 23 t $\times$ ha^{-1} heather compost was spread in September. In November the field was ploughed to 25 cm depth and in March 1984 oats were sown.

2.2. Inorganic nitrogen

Inorganic nitrogen was assessed to a depth of 120 cm. Separate samples were taken from 0—10, 10—30, 30—60, 60—90 and 90—120 cm with gouge-augers in 60 randomly taken replicates on each plot.

Measurement of inorganic nitrogen was based on colorimetry with a Technicon Autoanalyser, System II. Nitrogen contents are given in mg $\times$ kg^{-1} of oven-dry soil (dried at 105 °C). From 10 December the soil was at field capacity, and water was running from the field drains (at 1.20 m depth). This drain water was sampled and inorganic N was determined with the same colorimetric method.

2.3. Springtails

With a tube-auger (57 mm diameter) samples were taken to a depth of 20 cm with 10 replicates in each field. Collembola were collected from two separate layers: at 2.5—5 cm and 15.5—18 cm depth respectively. The soil samples were placed in extraction containers (volume 58 ml), which were then placed on collection containers with a 1% picric-acid solution and some detergent. Mesofauna was extracted over a period of one week in a high gradient extractor (VAN STRAALEN & RIJNINKS 1982). By the use of a light-dimmer, a daily rise of temperature was obtained to a maximum of 35 °C. Collection containers were cooled with cold tap water (about 13 °C). Collembola were cleared and identified in GISIN's medium (GISIN 1960).

2.4. Soil data

Bulk density was calculated from mass and volume data of the soil samples that were taken for Collembola extraction. Dry mass was measured from material oven dried at 105 °C. Soil temperatures were measured with thermistors at 0, 5 and 15 cm depth.

3. Results

3.1. Inorganic nitrogen

The quality of the newly added organic matter could explain the differences in organic and inorganic nitrogen in the two plots surveyed.

Winter wheat had had a preceding crop of sugar beet and leaf residues had been ploughed in (approximately 15 t $\times$ ha^{-1}). This material had a nitrogen content of approximately 2% and the humification coefficient was low (hc = 0.2) (JANSSEN, 1984; KOLENBRANDER, 1969). Mineralization of nitrogen prevailed during the first year after ploughing. This corresponds to the relatively low content of organic nitrogen (1.4 t $\times$ ha^{-1}) in October (table 1) in the

Table 1. Basic soil analysis data from the winter wheat field and the clover-grass ley

Site	Depth [cm]	Soil C [%]	Organic matter [t × ha^{-1}]	Soil N [%]	Total N [t × ha^{-1}]	C/N
clover-grass ley	0—10	2.4	60.4	0.20	2.92	12.0
	10—30	1.5	69.8	0.12	3.24	12.5
winter wheat	0—0	2.3	43.2	0.13	1.42	17.7
	10—30	2.3	97.6	0.13	3.20	17.7

Note: All of the data relate to samples collected on 13 October 1983.

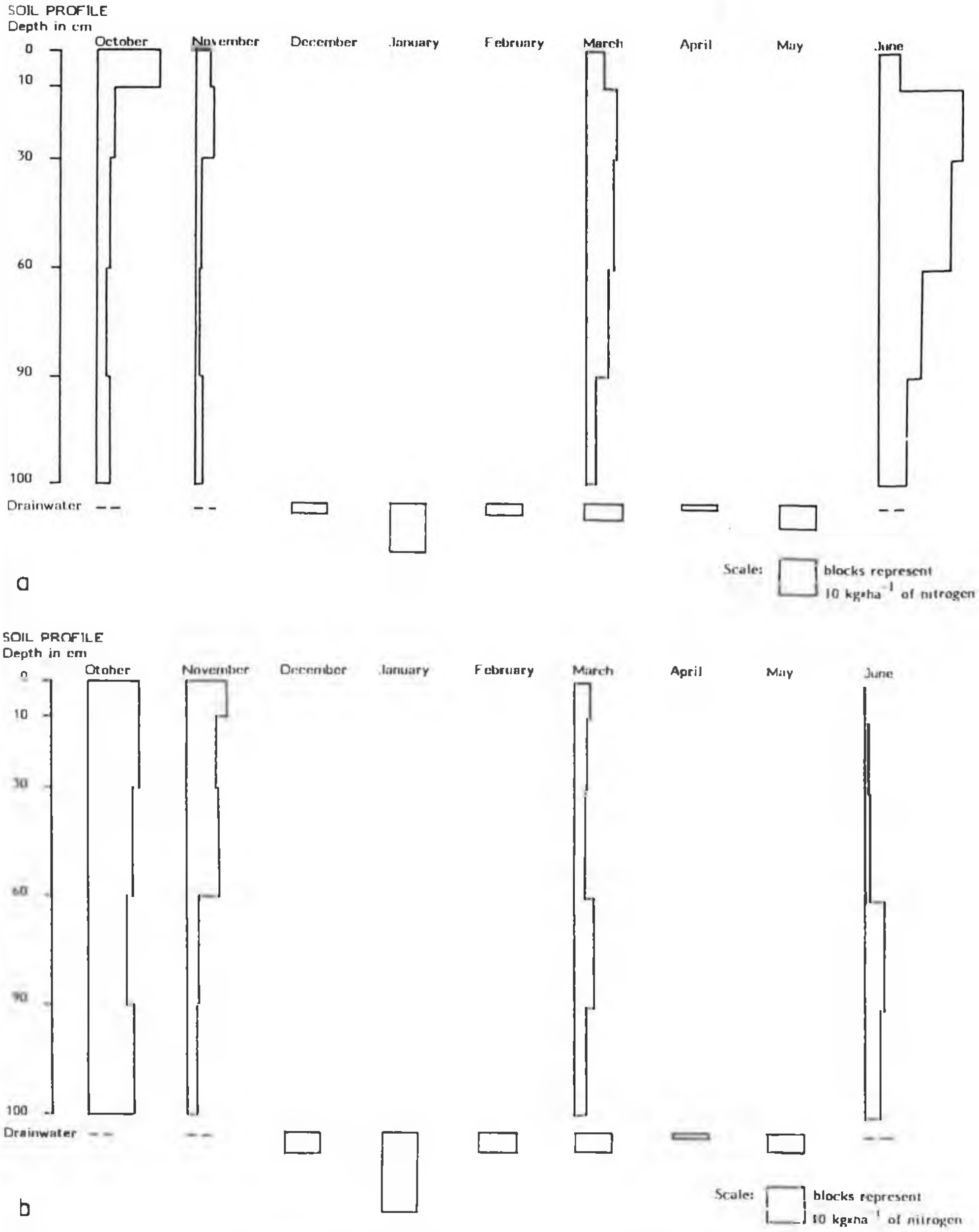
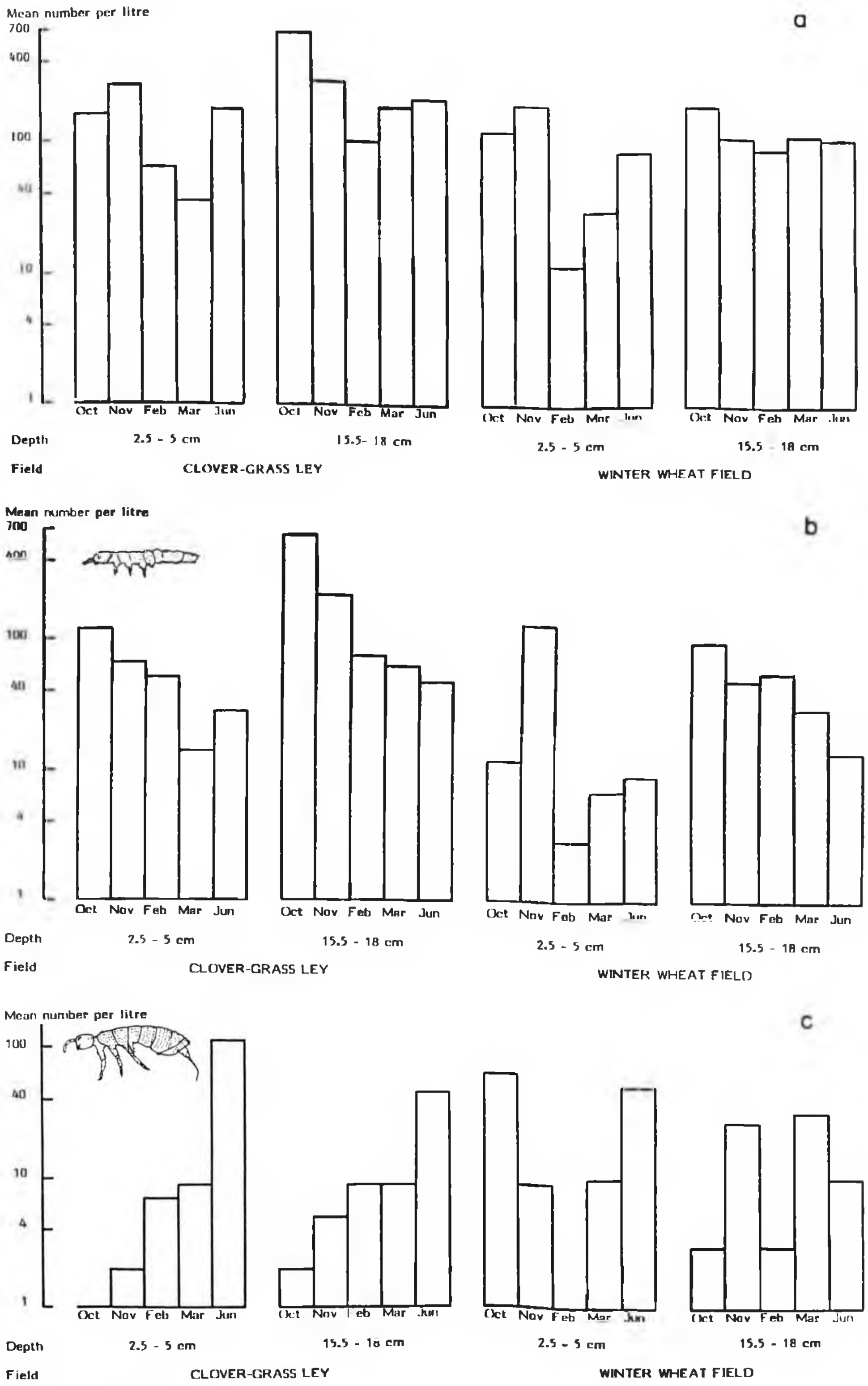


Fig. 1. Inorganic nitrogen, such as nitrate and ammonium, expressed as kg $\times$ ha^{-1} of nitrogen in layers of 10 cm depth, in the soil profile and in water running from the field drains at 1.20 m depth. Data were collected between October 1983 and June 1984 from (a) a clover-grass ley before ploughing, after ploughing (on 24 October) and after potato planting (16 April), and (b) a field after a winter wheat crop before ploughing, after ploughing (on 2 November) and after sowing of oats (19 March).


a
Mean number per litre
700
400
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10
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1
Oct Nov Feb Mar Jun
Depth
2.5 - 5 cm
15.5- 18 cm
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15.5 - 18 cm
Field
CLOVER-GRASS LEY
WINTER WHEAT FIELD
b
Mean number per litre
700
400
100
40
10
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1
Oct Nov Feb Mar Jun
Depth
2.5 - 5 cm
15.5 - 18 cm
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Field
CLOVER-GRASS LEY
WINTER WHEAT FIELD
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Mean number per litre
100
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WINTER WHEAT FIELD

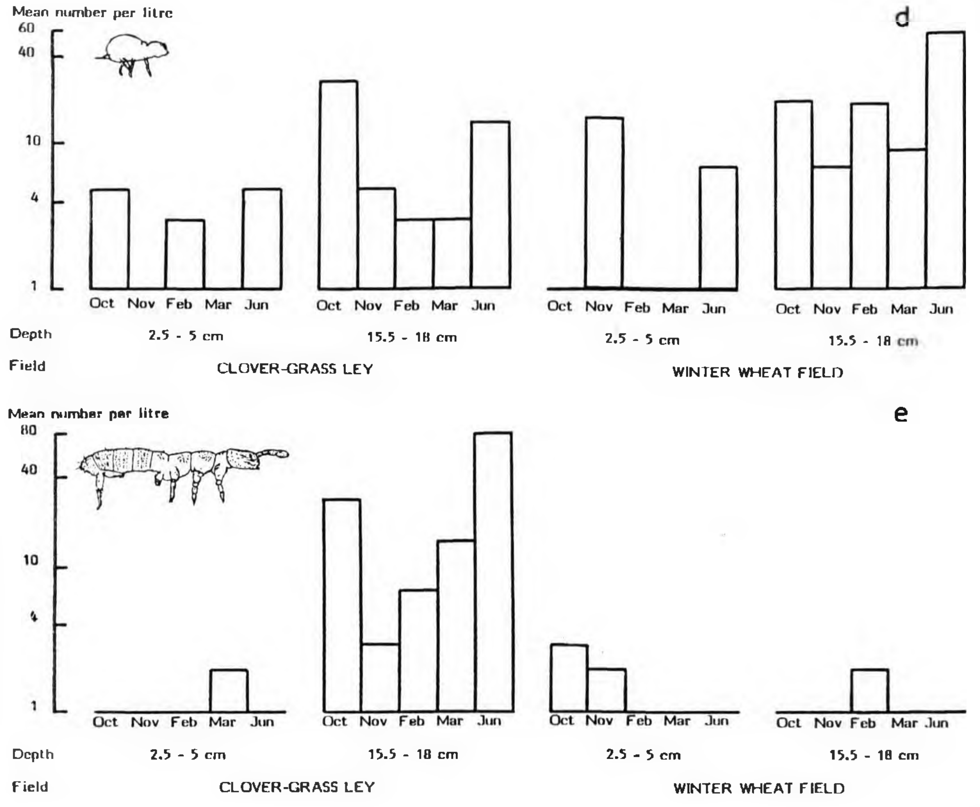

Fig. 2. Average numbers of Collembola, expressed as number per litre of soil, from autumn to spring. Collembola were collected from a field after a winter wheat crop and from a clover-grass ley before and after ploughing, at depths of 2.5—5 cm and 15. 5—18 cm. The five illustrations represent (a) total number of Collembola, (b) *Tullbergia krausbaueri s. l.*, (c) *Isotoma notabilis*, (d) *Neelus minimus*, and (e) *Cryptopygus gisini*.

top 10 cm of the cultivated layer. At the same time, the total profile, up to a depth of 120 cm, contained 148 kg $\times$ ha^{-1} inorganic nitrogen.

Ploughing in of the wheat stubble in October added organic matter with a large humification coefficient (hc = 0.40) and a low nitrogen content (wheat-root 0.66 %, wheat stubble 1.5 %) (VERVEDA 1984; KOLENBRANDER 1969). The mineralization of nitrogen had occurred after one year, at which time the surplus carbon had been respired. The soil profile was nearly devoid of nitrate in spring. This was the result of nitrogen immobilization after ploughing in of the carbon-rich wheat stubble and leaching of nitrogen (40 kg $\times$ ha^{-1}) from the subsoil in the winter period, which resulted in large NO_3 contents (up to 21 mg $\times$ l^{-1}) in the drain water in January (fig. 1b).

On the grass-ley plot the majority of the organic matter was to be found in the top 10 cm of the cultivated soil (60.4 t $\times$ ha^{-1}, table 1). This layer contained 2.9 t $\times$ ha^{-1} of organic nitrogen. During the previous three years the sward had developed satisfactorily and hence the organic matter consisted mainly of grass roots with an intermediate humification coefficient (hc = 0.30) and a nitrogen content of 2 % (VERVEDA 1984; KOLENBRANDER 1969).

At the first sampling occasion the sward had not been ploughed, so the roots were able to absorb all mineralized nitrogen. Up to a depth of 1.20 m only 52 kg $\times$ h^{-1} of organic nitrogen were present (fig. 1a). With ploughing, the aerial portions of the clover and grass, with a large nitrogen content (3 %) and small humification coefficient (hc = 0.20), were also added to the soil and formed 12.5 % of the soil organic matter (VERVEDA 1984; KOLENBRAN-

DER 1969). Mineralization of NO_3 could proceed rapidly in the spring of 1984. Also from the loose stable manure with a C/N ratio of 14.5, that was added in autumn 1983, nitrogen was released by mineralization.

3.2. Springtails

The total number of Collembola decreased in the winter, was lowest in February and increased again in the spring (fig. 2a). Temperature followed the same pattern and was lowest in February when the soil of the winter wheat field was frozen to a depth of 7 cm, and the ley to 10 cm (table 2). *Tullbergia krausbaueri s. l.*, which belongs to the euedaphon, was the most abundant species (fig. 2b). The largest specimen of this species had a length of 0.7 mm. MILNE 1962; HÖLLER-LAND 1962 have reported that there is a maximum population density in the autumn. Our results confirm this phenology.

Table 2. Soil temperatures during the sampling period, from autumn to spring

Date depth [cm]	13 Oct. 1983	9 Nov. 1983	16 Feb. 1984	13 Mar. 1984	4 Jun. 1984
0	15.3	13.8	<0	6.3	13.7
−5	13.3	11.1	<0	4.6	13.6
−15	12.6	10.0	>0	4.0	13.8

Note: The temperatures are the averages of those from the winter wheat field and the clover grass ley.

In the ley *T. krausbaueri* was the dominant species from October to February, during which time it contributed over 80% of the total number of Collembola. The maximum density found was 625 individuals $\times$ l^{-1} in October, before ploughing. This maximum might be due to several factors besides its phenology. One is that, in the ley, the dead roots of the clover and grass had been decaying for up to 3 years and presumably formed a soil with a high humus content. *T. krausbaueri* prefers a soil where dispersed humus is well mixed with mineral matter (SCHALLER 1950; BOCKEMÜHL 1966). Another factor is the high bulk density of 1.41—1.35 kg $\times$ l^{-1} (fig. 3) of this field in October, caused by the three years of trampling by cows. As *T. krausbaueri* prefers pores that surround its body tightly and is able to burrow its own pores (SCHALLER 1950; BOCKEMÜHL 1966) it was likely to develop a large population in this field. The sharp drop between October and November could be the result of ploughing. After ploughing the bulk density of the upper layer dropped from 1.46 kg $\times$ l^{-1} to 1.15 kg $\times$ l^{-1} (fig. 3), whereas the bulk density of the lower layer remained virtually constant (1.35 kg $\times$ l^{-1} before and 1.30 kg $\times$ l^{-1} after ploughing). Air had been brought into the soil and the ploughing had resulted in the animals of the upper part of the soil being moved down, and *vice versa*.

The hemiedaphic species *Isotoma notabilis* grows to a length of 2.0 mm. It occurs where organic matter is decaying and it lives partly on fungi (BÖDVARSSON 1970; HÅGVAR & KJØNDAL 1981). *I. notabilis* has a recorded maximum population density in arable land during spring and summer (HÖLLER-LAND 1959, 1962). Initially the high bulk density in the ley will have obstructed the development of *I. notabilis* (October and November maximum of 5 specimens/l) (Fig. 2c). After ploughing, the bulk density in the upper layer decreased and at a depth of 17 cm the former sward was often found in the samples. Apart from the seasonal influence these two factors will have contributed to the strong increase in the number of *I. notabilis* in the spring (at the top of the cultivated layer this was 111 specimens $\times$ l^{-1}). The population density of *I. notabilis* in the winter wheat soil was highest in autumn with 63 specimens $\times$ l^{-1}, compared to 51 sp. $\times$ l^{-1} in June. This will have been due to the decaying wheat stubble in the autumn. The presence of *I. notabilis* in wheat soil at a depth of 15.5—18 cm is the result of vertical migration (27 specimens $\times$ l^{-1} in November, 32 specimens $\times$ l^{-1} in March) as described by HÖLLER-LAND (1962) and DUNGER (1983).

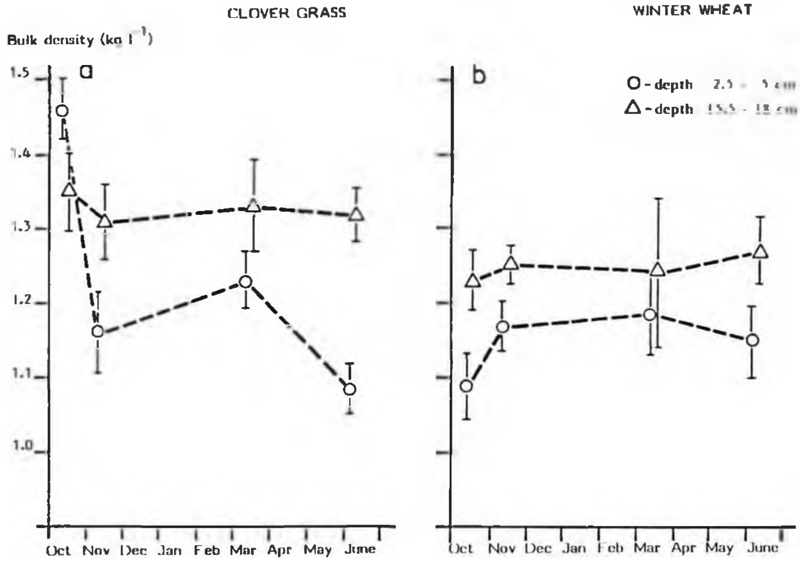

Fig. 3. Changes in the bulk density (kg × l^{-1}) of the soil from autumn to spring at two depths (○: 2.5—5 cm; △: 15.5—18 cm). The bars indicate 80% confidence limits, based on an assumption of the normal distribution. Data were collected from (a) a clover-grass ley before ploughing, after ploughing (on 24 October) and after potato planting (16 April), (b) a field after a winter wheat crop before ploughing, after ploughing (on 2 November) and after sowing of oats (19 March).

Neelus minimus is an euedaphic species that grows to a maximum length of 0.4 mm. *N. minimus* has a preference for soils with decayed organic matter (Höller-Land 1962) and, as it is a very small species, it is likely to ingest organic matter mixed with fine mineral particles (Schaller 1950; Mignolet 1972; Petersen 1980). In the 15.5—18 cm layer of the wheat soil, *N. minimus* occurred at a population density of 58 individuals × l^{-1} (fig. 2d), probably developing on the residues of the wheat stubble.

Cryptopygus gisini Massoud & Rapoport, which is also euedaphic, has not previously been recorded in The Netherlands. It reaches a length of 2.0 mm, is blind, and is rather larger and more mobile than other euedaphic species. In the 15.5—18 cm layer of the ley soil, it occurred in June with a density of 80 individuals × l^{-1} (fig. 2e) and it was mainly present in samples containing recognizable parts of the sward (75% of the specimens). Most probably, from its shape, length and lifeform, *C. gisini* is a selective fungivore species (Mignolet 1972), living in the larger dark cavities within the decaying fresh organic matter in the soil.

4. Discussion and hypothesis

When combining the results on bulk density, humification coefficients and occurrence of the most abundant species of Collembola it is obvious that where a low bulk density is combined with a low humification coefficient of organic matter, large numbers of relatively large (greater than 2 mm) and mobile Collembola such as *Isotoma notabilis* and *Cryptopygus gisini* occur. In this situation the process of mineralization is prevalent. Where a high bulk density and organic matter with a high humification coefficient occur together this is associated with large numbers of relatively small (less than 1 mm) and immobile Collembola like *Tullbergia krausbaueri* and *Neelus minimus*. In this situation the humification process prevails.

Visser (1985) and Anderson *et al.* (1984) suggested that fungal growth is greatest in soils with large pore size, allowing fungal sporulation. Fine textured soils have poor fungal de-

velopment. BÖDVARSSON (1970) stated that fungal hyphae are the most nutritious ingredient of the food of Collembola, and PETERSEN (1980) stressed this when he wrote "The euedaphic species are obliged to feed more or less continuously on a poor food, whereas the hemiedaphic species at the other extreme spend much time and energy in search of better quality foods".

HÅGVAR and KJØNDAL (1981) reported a succession in decaying birch leaves from atmobios, litter fauna to deeper-living forms. At the same time (JANSSEN 1984), the decomposition rate of the organic matter decreases and there is a tendency to find more amorphous matter in animal guts. In HÅGVAR and KJØNDAL's study, *Isotoma notabilis* (hemiedaphon) appeared after about three years in the litter bags. Smaller, euedaphic species were not recorded before the end of the experiment, though they may have been expected to appear when the decomposition rate had decreased still further.

Combining these studies it appears that the larger species of Collembola live in soils with larger pore sizes, with fungal growth and relatively fresh organic matter with a high decomposition rate; conversely, the smaller species live in the finer textured soils, where fungal growth is small or absent and the organic matter is relatively "old" with a low decomposition rate. Thus the larger species can feed selectively on the nutritious fungal hyphae whereas the smaller ones have to take up humus and mineral particles in order to digest the bacterial material in it.

The hypothesis that results from these findings is that the activity of the smaller species, for example *T. krausbaueri* and *N. minimus*, may contribute to the humification of soil organic matter (mineralization is low since there is a low decomposition rate of the soil organic matter, and the animals mix organic matter with mineral particles in their guts). The larger species, for example *I. notabilis* and *C. gisini*, stimulate the growth of fungi by grazing them (SEASTEDT 1984; VISSER 1985). This will stimulate the mineralization (which is high here, where the decomposition rate is high) of soil organic matter.

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From October 1983 to June 1984 we sampled the inorganic nitrogen content both in the soil profile to a depth of 120 cm and in the water from field drains. The population density of springtails in the cultivated layer was also determined. Sampling took place on two arable fields that were left fallow during the winter after ploughing; the preceding crops had been winter wheat in one field and a 3-year clover-grass ley in the other.

In the winter wheat field, in October, soil organic matter with a large C : N ratio was present together with a large amout of inorganic nitrogen (as nitrate and ammonium). This nitrogen was partly leached during winter and was partly immobilized in the carbon-rich wheat stubble. In October and November mainly *Tullbergia krausbaueri s. l.* and *Isotoma notabilis* were found in this field, whereas in June *Neelus minimus* and *I. notabilis* were predominant.

In the clover-grass ley, in October, the soil organic matter was present with a low C : N ratio. The amount of mineralized inorganic nitrogen increased from October to June. In the autumn *T. krausbaueri* was dominant, but it decreased in numbers during the winter. *I. notabilis* and *C. gisini* increased in population density in the spring.

From these observations, and from reports in the literature, it was concluded that the larger springtails (*I. notabilis* and *C. gisini*) stimulate mineralization processes by selective feeding on fungi. Smaller springtails (*T. krausbaueri* and *N. minimus*) contribute to humification by non-selective scavenging and mixing of organic material and mineral soil particles.

Key words: winter wheat, clover-grass ley, nitrogen, mineralization, humification, Collembola, food selection.